SPECTRAL CHARACTERISTICS OF LUNAR IMPACT MELTS: IMPLICATIONS FOR REMOTE SENSING

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Introduction: Remote geochemical mapping of lunar impact melt associated with complex craters may provide a key to better understanding of impact melt formation and the impact cratering process. Ground-based NIR spectra and Clementine multispectral images provide high-resolution spectral and spatial information, respectively, about lunar impact melts. As part of an effort towards improving our ability to interpret these data, two suites of lunar samples have been measured in NASA's Reflectance Experiment Laboratory (RELAB) at Brown University. The samples include seven Apollo 17 crystalline impact melts as well as synthesized glass equivalents (Suite 1), and 15 naturally occurring impact melts from four landing sites (Suite 2). The naturally occurring melts have a range of textures and compositions related to glass abundance.

Lunar Samples: Suite 1 crystalline samples were received as <125 µm powders. Six of the seven samples are inferred to be from the Serenitatis impact, but nonetheless span a range in composition, grainsize, and texture (1, 2). The glass samples were beads prepared at Johnson Space Center by fusion of a portion of each crystalline sample on Mo strips in an argon atmosphere (2). The beads were crushed to <125 µm particle size. Spectra for each Apollo 17 sample and its glass equivalent were measured independently, and for one crystalline-glass pair (76015) as a series of mass fraction mixtures.

The fifteen naturally occurring impact melt samples of Suite 2 were collected at the Apollo 12, 15, 16 and 17 landing sites. They have a range of textures, mineralogical compositions, and glass abundance. Although many of these are presumably from basin-forming impacts rather than craters, they are still impact melt rocks, and provide a useful start towards developing a sample database of impact melts for further study. Suite 2 samples were received as rock chips, and ground to <125 µm powders (after initial spectral measurements were made of various chip faces). Spectra for the bulk powders were measured, and selected samples sieved into four particle size separates: 45 - 75 µm, 25 - 45 µm, <25 µm (dry sieved), and <25 µm (wet sieved with ethanol, and presumed to include the very finest particles). The sample spectra presented below were measured in the RELAB bi-directional reflectance spectrometer from 0.3 to 2.6 µm (i=0°, e=30°).

Impact Melt Spectra: Spectra for each sample have been examined and grouped based on spectral properties such as the shape of the 1 and 2 µm absorption features, due to pyroxene and glass, as well as the presence of both a 1.2 µm feature (probably due to crystalline plagioclase) and a 0.6 µm absorption, which may be due to ilmenite (3) (Figure 1). From these analyses, several conclusions may be drawn about the spectral properties of lunar impact melts.

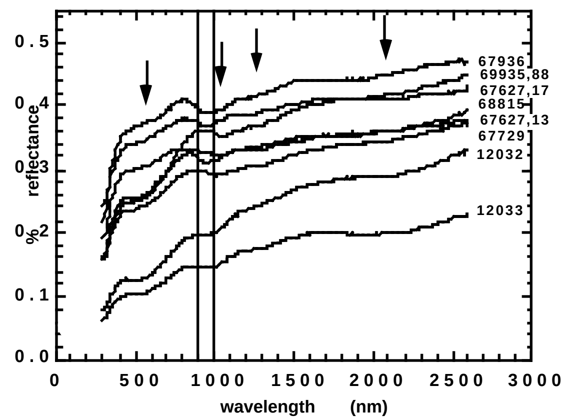

Figure 1 *Examples of naturally occurring melt spectra, with key spectral features indicated by arrow. The vertical lines at 900 and 1000 nm are a visual guide for comparing the position of the mafic absorption bands near 1 µm.*

1) Of the naturally occurring melt spectra, two categories are comparable to remote measurements in existing data sets. One group is indistinguishable from the spectra of crystalline igneous rocks, which are commonly observed in basin rings and central peaks of impact craters. This group contains the least glass, and has the slowest cooling history. The other group appears to be directly comparable to the NIR spectra of melt at Copernicus, Tycho, and Aristillus, which may contain large quantities of glass.

2) Mixtures of crystalline and glass samples of the same compositions suggest that lunar impact melts at the craters Tycho and Copernicus may consist of approximately equal amounts of glass and crystalline material. The crystalline component of the impact spectra appears to depend on the mineral composition of the target material at each crater, but the glass component varies little between craters (Figure 2).

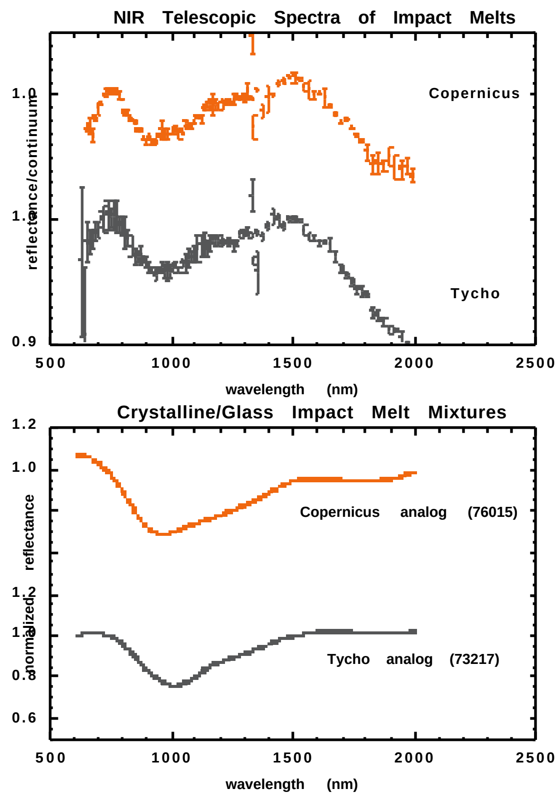

Figure 2 *Comparison between telescopic NIR spectra for impact melt on the Moon to mixtures of laboratory samples. The Copernicus analog is rich in low-Ca pyroxene and the Tycho example in high-Ca pyroxene. The difference in absorption band position that results from the different pyroxene composition affects the apparent shape of the mixture spectrum.*

3) The correlation between the abundance of FeO and TiO_2 and the spectral properties of lunar glass at visible wavelengths that were predicted by (4) can be detected at wavelengths for which both Clementine and Galileo instruments have acquired image data. However, these same spectral parameters are not correlated to composition for crystalline materials (Figure 3). Compositional estimates for impact melt based on remotely acquired spectra of the lunar surface depend upon assumptions of glass and crystal abundance. At craters like Copernicus and Tycho, *relative* estimates of FeO+TiO_2 content might ultimately be possible, if the glass/crystal ratio is similar.

4) Abundant glass may be responsible for the relatively "red" character of recognized impact melts, as measured by the strong spectral ratio between the 0.41 and 0.75 µm bands in Clementine (and similar Galileo wavelengths) multispectral image data (5). The strong reflectance peak at visible wavelengths apparent in the laboratory spectra of glasses leads to an apparent increase in redness (relative to crystalline sample spectra) based on those two wavelengths alone.

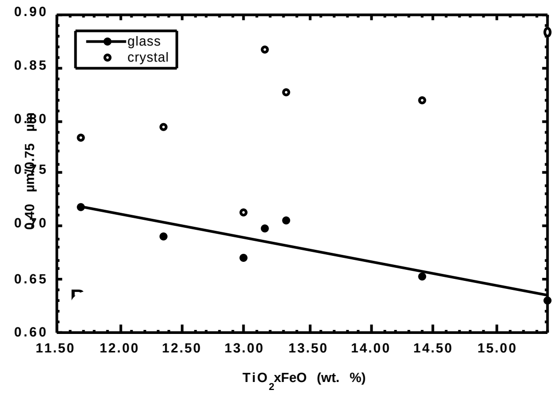

Figure 3 *Varibility of the 415 nm/750 nm ratio value for crystalline and glass material. The ratio is correlated to FeOxTiO² for glass, and is also uniformly lower (spectrally redder) for glass than for crystalline material of the same composition.*

5) Most of the naturally occurring melts studied have very fine grained textures indicative of rapid cooling, but fall short of quenching. Rather than being mixtures between two compositional end-members (crystal and glass), these rapidly cooled melts exhibit distinct spectral characteristics which have not been observed in remote measurements. The 0.6 µm absorption band, which appears in both suites of samples, is probably linked to the occurrence of fine grained ilmenite. The strength of the absorption band appears to first order to be more dependent on texture (i.e., ilmenite grain shape and size, and the optical properties of the matrix) than on mineral abundance.

Although these data represent only a first attempt at systematic, laboratory measurements of impact melt spectra, they exhibit a consistency in spectral properties that appear to be linked to cooling rate and (consequently) glass abundance and texture. Some of these spectral features may be examined directly in remote multispectral data, and others must wait for future remote data sets with the necessary braoder wavelength range.

References: 1. S. Tompkins et al., *Lun. Planet. Sci. Conf. XXVII* , 1335-1336 (1996). 2. G. Ryder, K. Stockstill, *Lun. Planet. Sci. Conf.* **XXVI**, 1209-1210 (1995). 3. C. M. Pieters, G. J. Taylor, *Proc. Lunar Planet. Sci. Conf.* **19th**, 115-125 (1989). 4. P. M. Bell et al., *Proc. Lunar Planet. Sci. Conf.* **7th**, 2543-2559 (1976). 5. C. M. Pieters et al., *Science* **266**, 1844-1848 (1994).